Proposal and Fabrication of Optically Pumped GaInAsP/InP Laser with Resonant Pumping

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1. Introduction

The rate of Internet access is rapidly growing over the world. Much higher capacity in Wavelength Division Multiplexing (WDM) systems is highly expected to avoid the crush of demand in market. Raman fiber amplifiers and its high power pump lasers are the key components to open up new wavelength bands and increase the total transmission capacity [1]. High power lasers to show watt-class output power and operate in a wavelength range of 1.1~1.6 μm are desirable for extending the available band in WDM systems with broadband Raman amplifiers.

Output power of over 450 mW has been achieved with a narrow stripe 1480 nm lasers[2], [3], but it is hard to realize watt-class high-power single-mode lasers due to heat generation. The heat problem arises from an excess applied voltage in current injection. In addition, the p-type doping causes optical absorption resulting in the efficiency deterioration of pump lasers.

We proposed an optically pumped GaInAsP/InP stripe laser with resonant pumping to increase a pumping efficiency. The design of a resonant cavity for efficient pumping is presented. The resonant vertical cavity is formed by low temperature InP-GaAs/AlAs DBR wafer bonding technique for realizing optically pumped high power lasers.

2. Design of optically resonant pumped lasers

Figure 1. shows the proposed structure of an optically pumped laser with a vertical resonant cavity. We can obtain a lasing wavelength in a wide spectral range of 1.1~1.6 μm by choosing an optimal composition of the active region. The pump source is a broad area high power 0.98 μm laser with several watt output which is commercially available. The proposed laser has a high reflectivity mirror at the bottom so that the active region is efficiently exited by focusing the output from the broad area pump laser. The resonant cavity was used for increasing the efficiency of photodiodes [4]. We carried out the similar analysis for increasing the pump efficiency. The theoretical model of the vertical resonant pumping is shown in Fig. 2.

By calculating multiple reflections in the resonant cavity, the normalized reflected power P_r and transmitted power P_t are written as follows,

$$P_r = \left| \frac{(1-R_1)\sqrt{R_2}\exp(-2jkL)\exp(-\alpha d)}{1-\sqrt{R_1 R_2}\exp(-2jkL)\exp(-\alpha d)} - \sqrt{R_1} \right|^2 \tag{1}$$

$$P_t = \left| \frac{\sqrt{(1-R_1)(1-R_2)}\exp(-jkL)\exp(-\frac{\alpha}{2}d)}{1-\sqrt{R_1 R_2}\exp(-2jkL)\exp(-\alpha d)} \right|^2 . \tag{2}$$

Where k is the wave number of the pump laser, the thickness and the absorption coefficient of an absorption layer are d and α, respectively, R_1 and R_2 is the power reflectivity of the top and the bottom mirrors, and L is the cavity length between the two mirrors.

Thus, the pump efficiency η is given by

$$\eta = 1-(P_r + P_t). \tag{3}$$

Figure 3 shows the calculated pump efficiency η as a function of various reflectivities of R_1, R_2. It is assumed that $\alpha = 2 \times 10^4$ cm^{-1}, d = 200 nm and L is defined to be matched with the standing wave of the pump laser. In the case of R_2 = 0.99, η is increased to 99 % at $R_1 \sim 0.45$. It is noticed that η is increased to 95 % at R_1 = 0.3, which is equivalent to the reflectivity at the boundary between semiconductor and air so that we do not need any additional coating on the top. High pump efficiency is expected by just increasing the reflectivity of the bottom mirror. Figure 4 shows the wavelength dependence of the pump efficiency. When the pump wavelength is changed by 2.5 nm from an optimal resonant wavelength, the pump efficiency decreases by 10 %. Thus, the tolerance of the pump wavelength is not critical for practical applications.

3. Fabrication of a resonant cavity by low temperature wafer bonding

As mentioned above, a high reflectivity mirror is needed at the bottom of the laser in order to increase the pump efficiency. We choose a GaAs/AlAs DBR, which has high reflectivity and better thermal resistance than other semiconductor DBRs, as a bottom mirror. The proposed structure was fabricated by wafer bonding technique. InP-GaAs/AlAs DBR wafer bonding has been carried out at ~600 °C, but such a high temperature bonding causes the thermal degradation, residual thermal stress problem and the defect migration from a fused interface[5]. To solve these problems, a 200 Å thick SiO_2 layer is deposited on the both wafers as a bonding layer for low temperature wafer bonding [6]. We could reduce the total thickness of SiO_2 to be 400 Å, which is 5 times thinner than the previous report [7].

A thin SiO_2 layer was deposited on the both wafers by plasma CVD. The both wafers were cleaned by methanol, acetone and followed by NH_3OH. The samples were rinsed and attached together in DI water without exposing them to the air. Then, the both wafers were annealed at 200 °C for 2 hours in N_2 atmosphere. After bonding, the GaAs substrate was polished, and InP substrate and the GaInAsP etch stop layer were removed by selective wet chemical etching. Figure 5. shows the cleaved facet of the fabricated structure, which was observed by a scanning focus ion beam microscope. As can be seen, a smooth bonding interface was obtained.

We realized the resonant cavity structure by InP-GaAs/AlAs DBR low temperature wafer bonding technique, which is useful not only for our proposed structure, but also for an optically pumped long wavelength vertical cavity surface emitting laser.

4. Conclusion

We proposed an optically pumped semiconductor laser with an enhanced absorption in a vertical resonant cavity. The calculated pump efficiency can be increased to ~99%. A Fabry-Perot resonant cavity structure was fabricated by a developed low temperature InP-GaAs/AlAs DBR wafer bonding technique. The proposed structure may have a potential of high power operation beyond one watt because of benefits in optical pumping, such as low excess power consumption and low optical absorption.

Acknowledgement

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References

[1] Y. Aoki: IEEE J. Lightwave Technol. **6** (1988) 1225.

[2] A. Kasukawa: Ext. Abstr. (Optical Society of America, Washington DC, 2000); Optical Fiber Communication Conference, OMC1-1A.

[3] A. Muthur, V. Dominic, S. DeMars, V. Agrawal, E. Vail, T.-J. Kim, A. Kanjamala and M. Ziari: Ext. Abstr. (Optical Society of America, Washington DC, 2000); Optical Fiber Communication Conference, OMC5-1.

[4] K. Kishino, M. S. Ünlü, J.-I. Chyi, J. Reed, L. Arsenault and H. Morkoç: IEEE J. Quantum Electron. **27** (1991) 2025.

[5] R. J. Ram, J. J. Dudley, J. E. Bowers, L. Yang, K. Carey, S. J. Rosner and K. Nauka: J. Appl. Phys. **78** (1995) 4227.

[6] H. Yokoi, T. Mizumoto, K. Maru and Y. Naito: Jpn. J. Appl. Phys. **36** (1997) 2784
[7] C. L. Chua, C. H. Lin, Z. H. Zhu, Y. H. Lo, M. Hong, J. P. Mannaerts, and R. Bhat: IEEE Photon. Technol. Lett. **6** (1994) 1400.

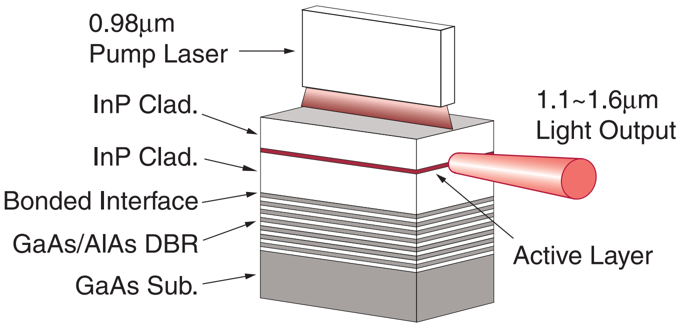

Fig. 1. Schematic structure of optically pumped GaInAsP/InP laser with resonant vertical pumping

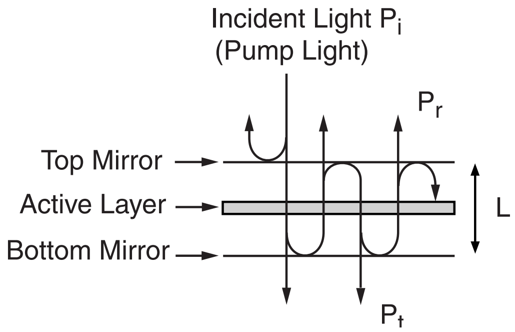

Fig. 2. Model of vertical resonant cavity for increasing pump efficiency

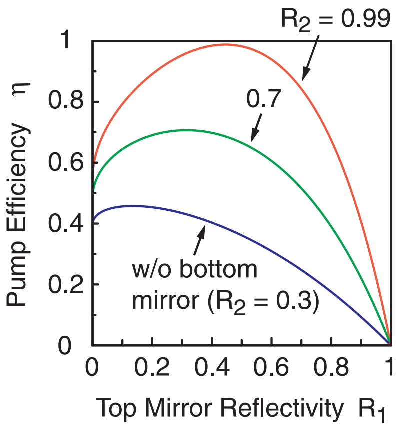

Fig. 3. Pump efficiency η as a function of reflectivities of mirrors R_1 and R_2

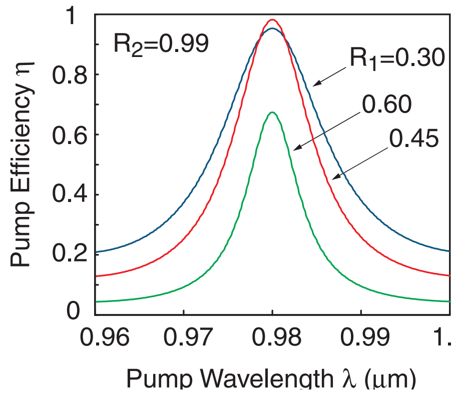

Fig. 4. Wavelength dependence of the pump efficiency

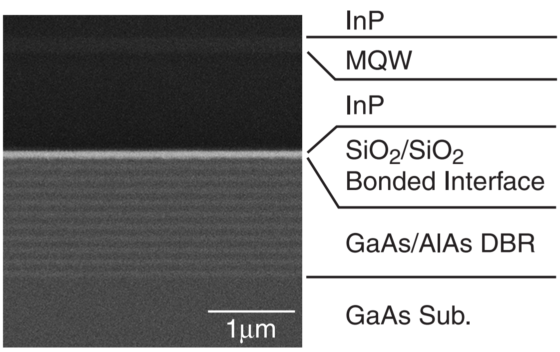

Fig. 5. Cross sectional focused ion beam (FIB) scanning microscope image of GaInAsP based laser bonded on a GaAs/AlAs DBR